Ionization and Acceleration of Radioactive Ion Beams at the 88” Cyclotron

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BEARS (Berkeley Experiments with Accelerated Radioactive Species) has been described in an earlier report [1]. As part of the BEARS project, radioactive species are cryogenically trapped, ionized in the AECR-U ion source, accelerated in the 88-Inch Cyclotron and delivered to one of several experimental areas. Maximizing the efficiencies for this process is an important element of the overall project. A second critical element is to minimize the contamination from other species. Both factors will contribute significantly to the applicability of this technique.

In initial studies, ^{11}C and ^{14}O were produced at the 88-Inch Cyclotron using protons from the ECR ion source. The activity (in the form of CO_2) was cryogenically trapped and then injected into the AECR-U. A NaI detector was used to measure the activity at the trap. After release into the AECR-U, the source was tuned and the charge states extracted, analyzed, and stopped in a Faraday Cup. The activity at the Faraday Cup was measured using a shielded Ge detector. After correction for half-life and detector efficiency, an ionization efficiency was calculated from the ratio of the two detector signals.

The ionization efficiencies are listed in Table 1 in comparison with those for the stable isotopes ^{12}C and ^{16}O measured with a calibrated CO_2 leak. The highest efficiency for a single radioactive ion species was 11% for $^{11}C^{+4}$, a factor of 2 lower than the efficiency for $^{12}C^{+4}$.

Acceleration of the $^{11}C^{+4}$ ions through the 88-Inch Cyclotron has been achieved in several test runs and the first physics experiment completed [2]. The highest intensity achieved was 1×10^{8} ^{11}C ions/sec at the experimental station

The analog beam ^{22}Ne is used to pre-tune the cyclotron, then the frequency shifted to ^{11}B and ^{11}C. The frequency difference is proportional to the mass difference between the species, the energy and the Cyclotron frequency. At E/A=10 MeV, ^{22}Ne and ^{11}C are separable, but not ^{11}C and ^{11}B. Therefore contamination from ^{11}B in the source becomes a large concern.

The first measurements of accelerated residual ^{11}B gave an intensity of <100 less than that of the ^{11}C beam. Subsequently, however, boron was run from the source for a different application and this led to increased ^{11}B intensities (a factor of 100 greater than the ^{11}C beam) even months later.

In order to reliably obtain a ^{11}C beam free of contamination, a stripper was placed between the Cyclotron and the main switching magnet. At E/A> 6 MeV, the stripping from $+4 \rightarrow +6$ is 99% efficient. For experiments at E/A≤ 1 MeV, if a boron-free beam is necessary it will become most efficient to tune $^{11}C^{+6}$ directly from the AECR. This will decrease the beam intensity from the source by a factor of ≈5, to 2×10^{7} ions/sec. In the near future, a development project will begin to explore ways to improve the mass resolution of the Cyclotron.

Footnotes and References

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1. J. Powell et al, this report
2. R. Joosten et al, this report

Table 1. Ionization Efficiencies

Ion	Ionization Efficiency (%)	
	RIBs	Stable Beams
$^{11,12}C^{+3}$	4	
$^{11,12}C^{+4}$	11	23
$^{11,12}C^{+5}$	4	15
$^{11,12}C^{+6}$	2	
$^{14,16}O^{+6}$	3.6	33
$^{14,16}O^{+7}$	1.2	7.4
$^{14,16}O^{+8}$	0.4	